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OPTIMIZING TAMARIND FRUIT DRINK PRODUCTION: A COMPREHENSIVE ANALYSIS OF PROCESSING METHODS, MASS BALANCE, AND ENERGY REQUIREMENTS

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Abstract: This study examined the impact of processing methods on the mass balance and energy requirement of tamarind fruit drinks. Four methods were compared: ultrasound pasteurization for seedless tamarind fruit drinks (UPST), hot extraction for seedless tamarind fruit drinks (HEST), ultrasound pasteurization for seeded tamarind fruit drinks (UPTWS), and vat pasteurization for seeded tamarind fruit drinks (VPTWS). Established equations were employed to estimate the mass and energy requirements. HEST and UPTWS produced the highest yields (2.8 kg), whereas UPST yielded the least (2.5 kg), and VPTWS exhibited a mass yield of 2.7 kg. Depodding consumed the most energy for UPST and HEST, while extraction dominated energy use for UPTWS and pasteurization for VPTWS. Energy inputs included manual and electrical sources, with UPST and HEST relying on manual energy, while UPTWS and VPTWS were dependent on electrical energy. Cumulative energy requirements for VPTWS, UPTWS, UPST, and HEST were 6.4376 MJ, 1.1007 MJ, 0.5969 MJ, and 0.5783 MJ, respectively. UPTWS was the most energy–efficient method and optimized yield for seeded tamarind fruit drinks, while HEST was the most efficient for seedless tamarind fruit drink. This study highlights the complex interplay between processing methods, mass balance, energy use, and yield in tamarind drink production.
Keywords: Tamarind, Ultrasound, Pasteurization, Energy requirement, Mass balance

1. INTRODUCTION

Tamarind (*Tamarindus indica*) is an arboreal fruit that belongs to the family of *Leguminosae*. It is locally known as *Awin* (Yoruba), *Tsamiya* (Hausa) and *Icheku* (Igbo) in Nigeria. It is a podded fruit that contains 55% pulp, 34% seed and 11% fibre and varied amount of shell (Muzaffar and Kumar 2017). The tamarind tree is a multipurpose tree whose parts are valuable both medicinally and nutritionally (De Caluwé et al. 2010; Singh et al. 2021; Joshi et al. 2023). India is the largest producer of tamarind with an average production of 191,750 tonnes between 2015–2016 (Muzaffar and Kumar 2017). The pulp serves as an essential part of the fruit that is recognized for its acidic taste, as well as constituents including pectin, protein, fibre, reducing sugar, tartaric acid, and cellulosic materials. However, their composition varies based on locality. In addition, the tamarind pulp is highly regarded as a good source of B–vitamins, high in phenolic content and minerals which include potassium, calcium, phosphorus, magnesium, and sodium (Balasubramanian et al. 2018). Tamarind seed is a very hard, shining, brownish or reddish substance found inside the pulp of tamarind. Tamarind seed is an underutilized raw material extracted from the tamarind pulp but is highly rich in protein, amino acid and some major sugars such as 20% pentose, 17–35% mannose and 11–80% glucose (Nagar et al. 2022).

Energy is one of the most consumed and considerable factors in the fruit juice processing industry. Energy analysis is an approach used to determine the total energy consumed and the cost of the consumed energy for a certain plant (Akinoso et al. 2013; Sanusi and Akinoso 2022). According to Anjorin et al. (2018), energy analysis of a processing line can be obtained through consideration of the source of energy, time taken and number of persons involved using the standard energy equation. In the fruit juice processing industries, increased yield and effective consumption of energy require a broad knowledge of mass balance and energy utilization of the unit operations involved in juice processing. The reduction of operating cost and total energy consumption to the minimum with an increased mass yield can be achieved by monitoring the operation involved strategically. As reported by Waheed et al. (2008), pasteurization as a unit operation during the production of fruit juice tends to consume the highest amount of energy. Also, Khanali et al. (2020) reported that the concentration of juice in the production of apple fruit juice consumes the highest amount of energy.

Ultrasound is a processing method that involves the use of acoustic waves with a frequency higher than 20 kHz which is capable of causing physicochemical change in product. Ultrasound is a novel technology and a means of achieving green technology and extraction. It is a technique known for its notable effect on different processes in the food industry (Dastkhoon et al. 2018; Bhargava et al. 2020). Ultrasound–assisted pasteurization has been deemed to be very efficient in deactivation of microorganisms such as

E.coli, Pseudomonas flourescens and *Listeria monocytogenes* with non–modification in the protein present (Cameron et al. 2009). The application of ultrasound pasteurization in the production of tamarind drinks could offer a promising approach to efficiently boost the yield and reduce energy consumption during processing. This study was performed to analyze variations in mass balance and energy requirements in tamarind fruit processing for tamarind drinks.

2. MATERIALS AND METHODS

Materials

The raw materials used for this study are tamarind fruits and sugar which were obtained from a local market in Ilorin, Kwara State, Nigeria. The unit operations involved in producing tamarind juice consist of washing, de–podding, sorting, blending/milling, extraction, vat pasteurization and ultrasound pasteurization.

Tamarind Fruit Drink Production

Tamarind fruits (6 kg) were washed to remove external contaminants such as sand prior to processing. The washed tamarind fruits were de–podded to remove the exocarp of the tamarind fruits. Manual sorting of the de–podded tamarind fruits was done by human operators to hand pick the defective fruits based on the ones with unacceptable colour. The washed fruits were divided into four portions; the first portion (1.5 kg) was partially blended to separate the pulp from the seeds. The partially blended tamarind was passed into an extraction tank where water was applied to achieve cold extraction. The extracted fruit drink was sieved and treated with ultrasonic cleaner (Model: CJ–008, China) as a means of achieving non–thermal pasteurization of the fruit drink to produce ultrasound pasteurized seedless tamarind fruit drink (UPST).

The second portion (1.5 kg) was partially blended to separate the pulp from the seeds. The partially blended tamarind was passed into an extraction tank where hot water was applied to achieve hot extraction. The extracted juice was sieved and packaged to achieve a hot extracted seedless tamarind fruit drink (HEST). The third portion of tamarind (1.5 kg) was milled using a fabricated hammer mill to crush the pulp and the seeds of the tamarind together. The crushed tamarind was passed into an extraction tank where water was added to achieve cold extraction and the extracted juice was sieved and divided into two lots. One lot was pasteurized using an ultrasound treatment for 30 min to achieve ultrasound pasteurized tamarind seeded fruit drink (UPTWS) while the second lot was vat pasteurized at 70°C for 30 min to obtain vat pasteurized tamarind seeded fruit drink (VPTWS). The pasteurized juice from the four (4) processing approaches were packed into a polypropylene bottle, sealed and kept in a refrigerating chamber at 5°C.

Mass Balance

The standard method for evaluating the mass balance in the tamarind processing line was expressed mathematically using Equation 1:

$$\mathrm{MO} = \mathrm{MI} - \sum \mathrm{ML} \qquad (1)$$

where MO is the Mass Output and is the total mass of the tamarind fruit drink, MI is the mass input is the initial mass of the raw tamarind and ∑ ML is the mass losses which represent the sum of all mass losses that occur during various processing stages, such as depodding, washing, sorting, extraction, sieving and pasteurization.

Energy Analysis

The conservation of energy is highly important in any processing technique. According to the first law of thermodynamics which states that energy can never be created nor destroyed but can be converted from one form to another. Parameters in Table 1 was employed to evaluate the energy requirement in the production of tamarind fruit drink.

— Electrical energy

The electrical energy usage for the sorting conveyor, hammer mill, and extraction tank were determined through the power rating of the electric motor, number of hours of operation, and the power factor (Waheed et al. 2008; Sanusi and Akinoso 2022). The electrical energy was evaluated as described in Equation 2.

$$E_p = \varphi \times P \times t \qquad (2)$$

where E_p is the electrical energy consumed in kW/h, P is the power rating of the electric motor in kW, t is the hour of operation in h, and φ is the power factor of the electric motor.

The electrical energy for the ultrasonic cleaner and blender was evaluated using Equation 3.

$$E_p = P \times t \qquad (3)$$

where E_p is electrical energy consumed in kW/h, P is the power consumption of the ultrasonic cleaner or the blender in kW, t is the hour of operation in h.

— Manual Energy

According to Sanusi and Akinoso (2021), the continuous energy consumption in any unit operation can be expressed in terms of humans and time taken to operate. The average power output of normal male labour in tropic climates is approximately 0.75 MJ/h sustained for an 8–10 h workday. The manual energy was evaluated as described in Equation 4.

$$E_m = 0.75 \times N \times t \qquad (4)$$

where E_m is the manual energy consumed in MJ, N is the number of persons involved in the operation, t is the useful time taken to accomplish a specific task and 0.75 is the average power output of a normal male labour in MJ/h.

Table 1: Parameters for evaluating the energy requirement in the production of tamarind fruit drink

Unit operation	Required parameter
Washing Conveyor	Number of persons involved in washing Time taken for washing(h)
Depodding	Time taken for the depodding (h) Number of persons involved in depodding
Sorting	Electrical power Time taken for sorting (h) Number of persons involved in sorting
Milling	Electrical power Time taken for the milling (h) Number of persons involved in milling
Blending	Electrical power Time taken for the blending (h)
Extraction tank	Electrical power Time taken (h)
Vat Pasteurizer	Electrical power Time taken for pasteurizing (h)
Ultrasound	Ultrasonic cleaner power Time taken for pasteurizing (h)

— Total energy requirement for the processing methods

The total energy requirement for each method of processing the tamarind fruit into fruit drink were using Equations 5, 6, 7 and 8 for UPST, HEST, UPTWS and VPTWS, respectively.

$$E_{UPST} = E_w + E_{dp} + E_s + E_{pb} + E_{si} + E_u \qquad (5)$$

$$E_{HEST} = E_w + E_{dp} + E_s + E_{pb} + E_{he} + E_{si} \qquad (6)$$

$$E_{UPTWS} = E_w + E_{dp} + E_s + E_m + E_{ce} + E_{si} + E_u \qquad (7)$$

$$E_{VPTWS} = E_w + E_{dp} + E_s + E_m + E_{ce} + E_{si} + E_{vp} \qquad (8)$$

where EUPST is the total energy requirement in the ultrasound pasteurized seedless tamarind fruit drink, EHEST is the hot extracted seedless tamarind fruit drink, EUPTWS is the energy requirement in the ultrasound pasteurized tamarind seeded fruit drink, EUPTWS is the vat pasteurized tamarind seeded fruit drink, Ew is the energy requirement in washing, Edp is the energy requirement in depodding, Es is the energy requirement in sorting, Em is the energy requirement in milling, Esi is the energy requirement in sieving, Ehe is the energy requirement in hot extraction, Ece is the energy requirement in cold extraction, Eu is the energy requirement in ultrasound pasteurization and Evp is the energy requirement in vat pasteurization. All the total energy were converted from kWh to mega joules (MJ) by using (1 kWh = 3.6 MJ).

3. RESULTS AND DISCUSSION

Effect of Processing Methods on the Mass Balance of Tamarind Fruit Drink

Mass balance is fundamental to the control of processing, particularly in the control of production yield. The mass balance was accounted for based on the input of 1.5 kg of tamarind fruits in the production of each tamarind fruit drink.

Figure 1 shows the mass balance involved in the production of ultrasound pasteurized seedless tamarind fruit drinks (UPST). The yield of the drink was estimated to be 2.5 kg (Figure 1). A mass loss of 0.09 kg, 0.21 kg, 0.2 kg, 0.2 kg, 2.1 kg and 0.2 kg was estimated for washing, depodding, sorting, blending, sieving and ultrasound pasteurization, respectively. A mass yield of 2.8 kg was estimated during the production of hot extracted seedless tamarind fruit drink (HEST). The mass loss in the production of tamarind juice drink HEST varies from one unit operation to another (Figure 2).

The estimated mass loss at each unit operation in the processing of tamarind fruits into ultrasound pasteurized tamarind for seeded fruit drink (UPTWS) is depicted in Figure 3. The mass yield evaluated in the production of tamarind juice drink UPTWS was 2.8 kg. A mass yield of 2.7 kg was estimated during the production of vat pasteurized tamarind for seeded fruit drink (VPTWS). The mass loss in the production of tamarind juice drink VPTWS varies from among the different processing operation (Figure 4). The highest mass loss in the production of UPST, HEST, UPTWS and VPTWS was observed during sieving with estimated mass value of 2.1 kg, 2.4 kg, 1.45 kg and 1.6 kg respectively. The highest mass loss during sieving maybe due to the separation of fine particles, seeds and fibrous solid from the liquid pulp which led to loss of substantial amount of solid components.

Figure 1: Mass and energy balance for production of tamarind juice drink ultrasound treated without seed (UPST)

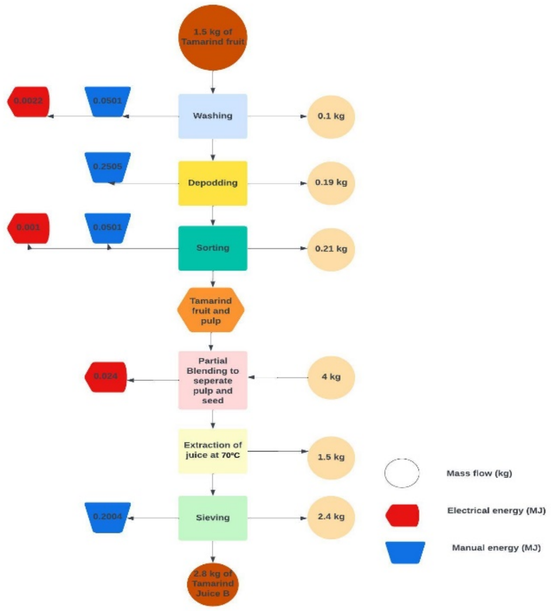

Figure 2: Mass and energy balance for production of tamarind juice drink pasteurized treated without seed (HEST)

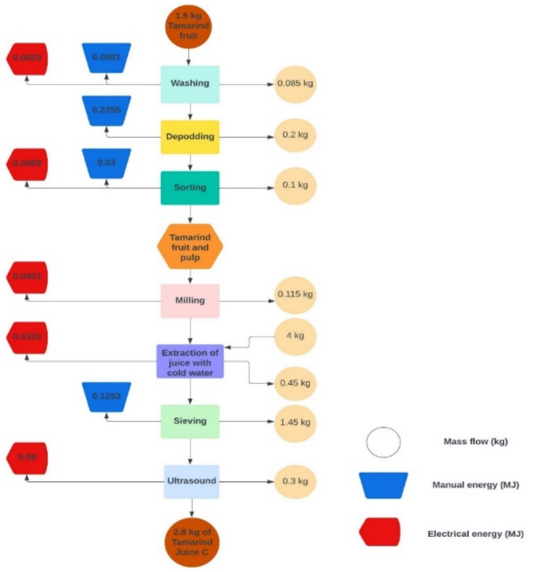

Figure 3: Mass and energy balance for production of tamarind juice drink ultrasound treated milled with seed (UTWS)

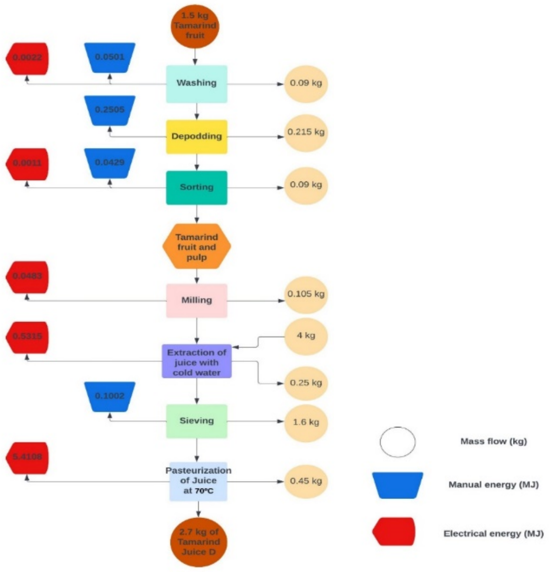

Figure 4: Mass and energy balance for production of tamarind juice drink vat pasteurized treated milled with seed (VPTWS)

Similar result was reported by Shoikhedbrod (2018) that sieving during production of juice can result in high mass loss due to the extraction of juice from the fruit pulp through application of ineffective sieving mechanism. The least mass loss was recorded during washing with the estimated mass value of 0.09 kg, 0.1 kg, 0.085 kg and 0.09 kg respectively.

Effect of Processing Methods on the Energy Requirement of Tamarind Fruit Drink

Due to the increasing cost of energy in the food industries, it is necessary to devise means of conserving energy during food processing. The energy balance was accounted for based on the input of 1.5 kg of tamarind fruits in the production of four (4) tamarind fruit drinks. The energy requirement at each unit operation in the processing of tamarind fruit into tamarind juice drink UPTS is depicted in Figure 1. The average amount of energy required in sieving, ultrasound pasteurization, sorting and washing were estimated to be 0.1753 MJ, 0.09 MJ, 0.0551 MJ and 0.0521 MJ respectively. As shown in Figure 2, the energy required in the processing of tamarind fruits into tamarind fruit drink (HEST) varies among the various unit processes used. The highest energy required in the production of tamarind fruit drink UPST and HEST was found in depodding with energy values of 0.2004 MJ and 0.2505 MJ, respectively. This may be attributed to the time taken to separate and remove the hull and pulp from the pod. The least energy required was recorded at blending with energy values of 0.024 MJ and 0.024 respectively. This result is because energy required at each unit operation is a function of the processing time at each unit operation (Sanusi and Akinoso 2022).

The energy required at each unit operation in the processing of tamarind fruit into tamarind fruit drink UPTWS is presented in Figure 3. The highest energy consumed was estimated at extraction with energy value of 0.5315 MJ while the least energy consumption was estimated at sorting with energy value of 0.0309 MJ. The energy consumption obtained in depodding, sieving, ultrasound pasteurization, washing and milling were 0.2255 MJ, 0.1253 MJ, 0.09 MJ, 0.0524 MJ and 0.0451 MJ respectively. The high amount of energy consumed during extraction may be attributed to the time taken to breakdown the cell walls, extract juice from the plant tissue and overcome the solid components to successfully achieve the desirable juice concentration. Similar result was reported by Modesto et al. (2009) that extraction is an energy–intensive unit operation in the production of juice.

The energy utilized in the processing of tamarind fruit into tamarind fruit drink VPTWS is depicted in Figure 4. The highest energy consumption was recorded at vat pasteurization with an estimated energy value of 5.4108 MJ while the least energy consumption was found at sorting with an estimated energy value of 0.044 MJ. The energy consumption obtained at extraction, depodding, sieving, washing and milling were 0.5315 MJ, 0.2505 MJ, 0.1002 MJ, 0.0523 MJ and 0.0483 MJ respectively. The highest amount of energy required during vat pasteurization may be as a result of the time taken to carry out the pasteurization operation to ensure the juice is health and safe for consumption. This result was similar to the findings of Waheed et al. (2008), that the highest energy consumed in the processing of juice was due to the pasteurization operation.

Forms of Energy Required in the Processing of Tamarind Fruit Drink

Two forms of energy were used in the processing of tamarind fruit into tamarind fruit drinks, which are electrical and manual energy. The forms of energy utilized in the processing of tamarind fruit drink UPST and HEST are presented in Figure 5(a) and 5(b) respectively. In the processing of tamarind fruit drink, UPTS and HEST manual energy consume the highest energy portion with estimated energy percentages of 80.4% and 95.3%, respectively while electrical energy took 19.6% and 4.7% respectively of the total utilized energy. Therefore, tamarind fruit drink UPTS and HEST processing is manual energy dependent. The processing of tamarind fruit drink UPTWS and VPTWS are depicted in Figure 5(c) and 5(d) respectively; electrical energy required the highest energy portion with 60.9% and 93.1% respectively while manual energy consumed 39.1% and 6.9% of the total energy utilized. This implies that the processing of tamarind fruit drink UPTWS and VPTWS are electrical energy dependent.

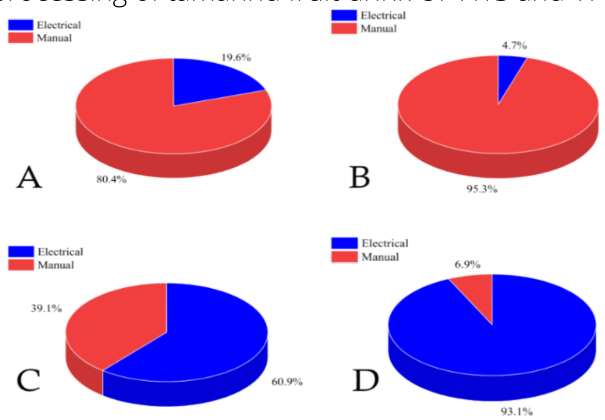

Figure 5: Forms of energy utilized in the production of tamarind juice, where A is the UPST, B is the HEST, C is the UPTWS and D is the VPTWS

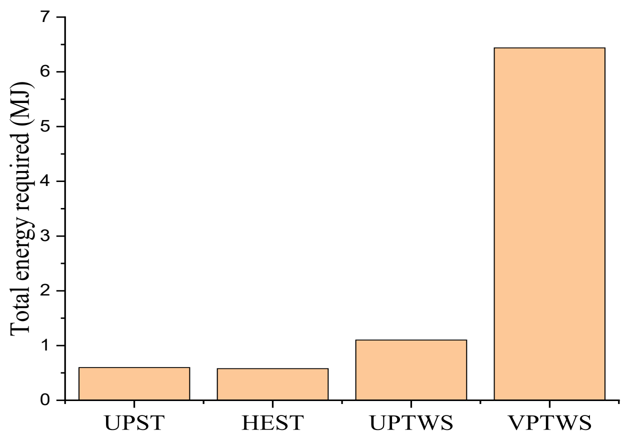

Figure 6: Total energy required in the production of tamarind juice drink

Total Energy Required in Processing of Tamarind Fruit Drink

The total energy required in the processing of tamarind fruit drink is represented in Figure 6. The processing of tamarind fruit drink VPTWS consumed the highest energy with the energy value of 6.4376 MJ while the least total energy consumed was during the production of tamarind fruit drink HEST with energy value of 0.5783 MJ. The total energy required in the processing of tamarind fruit drink UPTWS and UPST were 1.1007 MJ and 0.5969 MJ respectively. The highest energy required during the processing of tamarind fruit drink VPTWS was as a result of the pasteurization operation. The higher energy required in the production of tamarind fruit drink UPTWS and VPTWS can be attributed to the complexity involved in the processing method such as milling of seed which subsequently increase the energy required.

4. CONCLUSIONS

This study indicates that the mass balance and energy requirements for processing tamarind fruit into tamarind fruit drinks differ across various processing methods. Among these methods, the production of tamarind juice drink using the HEST and UPTWS approaches yielded the highest mass output of 2.8 kg per 1.5 kg of tamarind fruit processed, while the lowest yield was obtained in the UPST method with a mass output of 2.5 kg. Additionally, the mass balance for VPTWS production was estimated to be 2.7 kg. The study identifies the most energy–intensive operation for each processing method. The study reveals that the total minimum energy needed for producing tamarind juice drinks through UPST, HEST, UPTWS, and VPTWS methods is 0.024 MJ, 0.024 MJ, 0.0309 MJ, and 0.044 MJ, respectively. The study also highlights two primary sources of energy utilized in tamarind juice production: electrical and manual energy. Specifically, UPTS and HEST processing are manual energy dependent, while UPTWS and VPTWS methods are electrical energy dependent. Additionally, the total energy required in the tamarind fruit–to–tamarind fruit drink processing for VPTWS, UPTWS, UPTS, and HEST were estimated to be 6.4376 MJ, 1.1007 MJ, 0.5969 MJ, and 0.5783 MJ, respectively. Therefore, it is evident that UPTWS stands out as an energy–efficient approach that maximizes yield when processing with seeds. On the other hand, HEST demonstrates energy conservation and optimal yield when processing without seeds.

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